

# Scheme of Direct Time-domain Extrapolation in Half-space by FDTD Method

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## Abstract

A scheme of direct time-domain extrapolation to far fields in half-space by finite-difference time-domain (FDTD) method was proposed, called the time-domain three-wave extrapolation that was in agreement with the nature of FDTD. The result for scattering from a perfectly conducting circular cylinder in half-space validated the proposed scheme.

## Keywords

FDTD Method; Half-space; Time-domain Extrapolation

## Introduction

The finite-difference time-domain (FDTD) method holds the advantage of calculating all of the frequency components of the scattered field illuminated by a broadband transient pulse simultaneously. In free space, this technique calculates the time-domain response of the scattered field directly, and then broadband frequency response is obtained by carrying out a Fourier transform, which has been developed in the case of 3D (Yee *et al.*, 1991; Taflove *et al.*, 2005) and 2D (Luebbers *et al.*, 1992; Garcia *et al.*, 2000) respectively.

In half-space, however, FDTD is usually used to calculate the far-zone electromagnetics scattered field in various directions at a single frequency by the equivalent electromagnetic currents in near-zone (Wong *et al.*, 1996; Demarest *et al.*, 1996), which can be called the steady state calculation. Being a time-domain scheme, it is natural to calculate the time-domain response even for half-space case, but this result is seldom today. To our knowledge, the direct time-domain extrapolations to far-field for half-space case have been given by Martin *et al.* (2001) and Capoglu *et al.* (2006). The former is inherently a frequency method and the other follows the algorithm by using the complicated *convolution*.

This paper, on the basis of Snell's law (Harrington, 2001), proposed a new direct time-domain extrapolation scheme for FDTD in half-space for two-dimension case, and this scheme is consistent with the *on-the-fly* calculation of far field such as that proposed by Luebbers *et al.* (1992) and Garcia *et al.* (2000).

## Scheme

Shown in Fig. 1 is the *on-the-fly* calculation scheme for far field in the upper space. Let the half-space model constructed of the upper media (Media 0,  $\mu_0, \epsilon_0$ ) be free space and the lower media (Media 1,  $\mu_1, \epsilon_1$ ) be a lossless dielectric,  $C_i$  be the velocity in Media  $i$  and  $\varphi$  be the azimuth to far-zone point of  $P$ . For simplicity, the origin of  $y$ -axis was supposed to be on the interface. It was assumed that the transformation surface  $S$  straddles the interface and  $A_i$  be at the computational grid of  $(l \cdot \Delta x, m \cdot \Delta y)$  on  $S$  in Media  $i$ , and the wave vector of incident wave be  $k_i$ . Fig. 1(b) and (c) also show that  $O_{Ai}$  be the point of reflection and transmission respectively, which is used to be the projected point on the observation time in  $\varphi$ -direction, and  $t_{A0}$ ,  $t_{OA0}$  and  $t_{OA1}$  are the projection of  $A_0$ ,  $O_{A0}$  and  $O_{A1}$  on this time.

It can be seen that the far-field is composed of three components which are the fields radiated by equivalent source in upper space following the direct wave path and the reflected wave path and that in lower media following the transmitted wave path. The *on-the-fly* calculation following the direct wave path is the same as that in free space (Luebbers *et al.*, 1992; Garcia *et al.*, 2000), and the difference of this calculation between half-space and free-space lies in that following the later two paths, which should be modified. In what follows, the modification of *on-the-fly* calculation following the reflected and transmitted

wave paths would be illustrated.

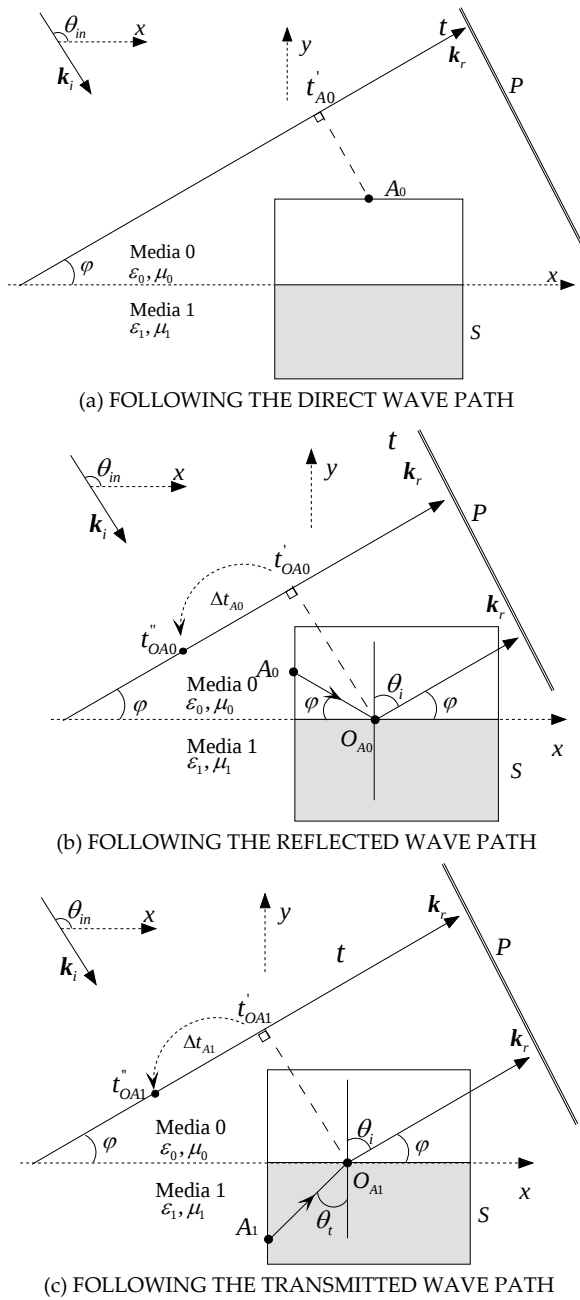


FIG.1 THE ON-THE-FLY CALCULATION OF FAR FIELD IN HALF-SPACE

#### a) The modification of projection

It is nearly impossible to project Point  $A_i$  on the observation time directly by the reflected and transmitted wave paths, but which can be realized indirectly by Point  $O_{Ai}$  as shown in Fig. 1(b) and (c). Considering  $t_{OA_i}$  is not the true projection of Point  $A_i$ , and the true that should be delayed with associated time of  $\Delta t_{Ai} = \overline{A_0O_{Ai}}/c_i$ , which can result in that the true projection is  $t_{OA_i}'' = t_{OA_i}' + \Delta t_{Ai}$ . Where  $\overline{A_0O_{Ai}} = m \cdot \Delta y / \sin \varphi$  and  $\overline{A_iO_{Ai}} = -m \cdot \Delta y / \cos \theta_i$  are the distance of Point  $A_i$

to Point  $O_{Ai}$ , the coordinates of Point  $O_{A0}$  and Point  $O_{Ai}$  are  $(l\Delta x + m\Delta y \cdot \tan \varphi, 0)$  and  $(l\Delta x - m\Delta y \cdot \tan \theta_i, 0)$ , and  $\theta_t = \arcsin(\sqrt{\mu_0 \epsilon_0 / \mu_1 \epsilon_1} \cos \varphi)$  is the transmission angle derived by Snell's law.

#### b) The modification of scale factor

The radiation field to the equivalent source at Point  $A_i$  following the direct wave path contributes to the far-field completely. However, the contribution following the reflected and transmitted wave path should be modified by the scale factor of Fresnel reflection coefficient ( $\tilde{R}$ ) and Fresnel transmission coefficient ( $\tilde{T}$ ) (Harrington, 2001) respectively.  $\tilde{R}$  and  $\tilde{T}$  have different expression for different polarized wave. It's very worth noting that the transmission should be from Media 1 to Media 0.

#### Validation

There are many half-space results of RCS versus azimuth by running steady state calculation. In this letter, such an example was listed as shown in the reference (Borghi *et al.*, 1996) to validate the scheme, in which a perfectly conducting circular cylinder with the radius of  $a$  is at a distance  $h$  from the interface. The relative permittivity of the dielectric in lower space is 4, i.e., the refractive index ( $n$ ) is 2, which is illuminated by a TM polarized Gaussian pulse with  $\theta_{in} = 90^\circ$  and  $\theta_{in} = 120^\circ$ . The FDTD code uses the following date:

1.  $a=0.5m$  and  $h=1m$ ;
2.  $\delta = \Delta x = \Delta y = 0.02m$ ;
3.  $\Delta t = \delta / (2c_0)$ ;
4. Gaussian pulse  $\exp(-4\pi(t-t_0)^2/\tau^2)$  with  $\tau = 60\Delta t$  and  $t_0 = 0.8\tau$ .

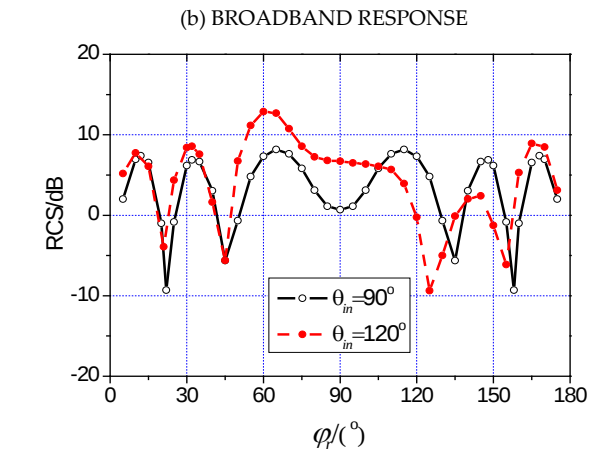
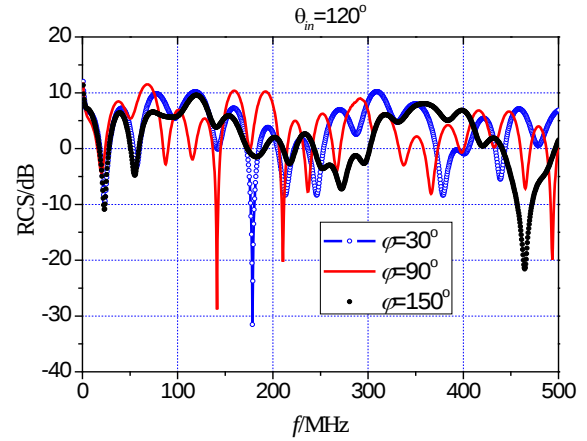
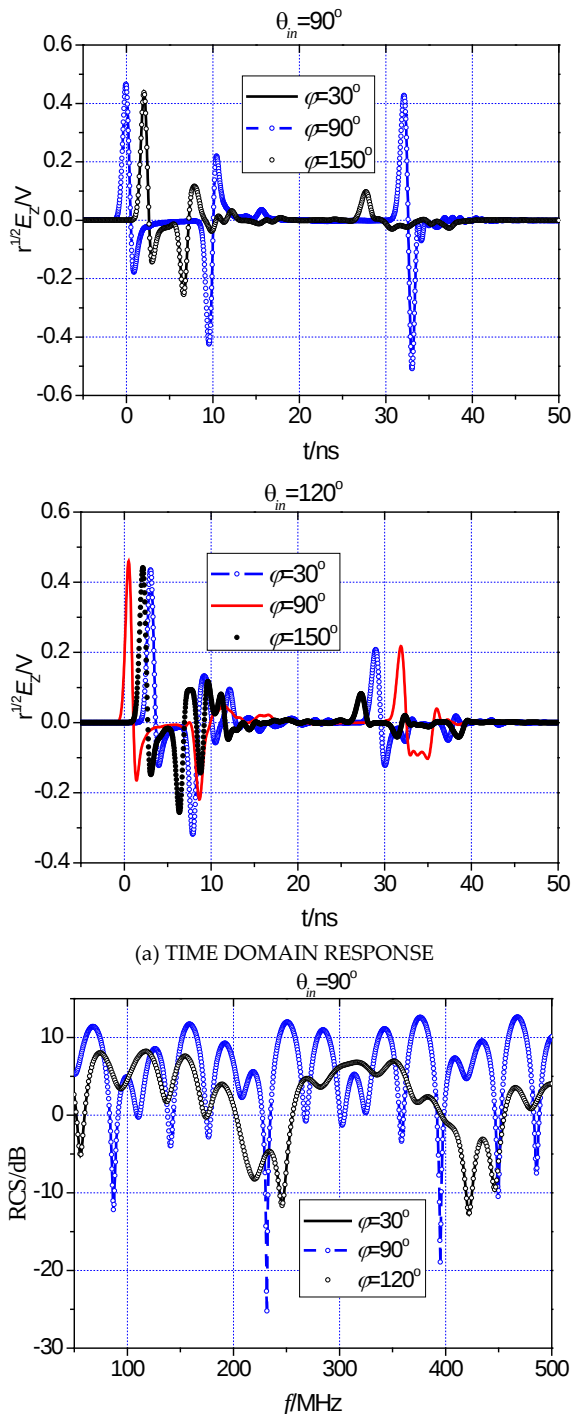
The validation is developed by following method:

1. Perform an FDTD calculation in many directions and Fourier transform to obtain the broadband frequency domain response of far-field in those directions.
2. Extract the values at one same frequency from the frequency domain response in various directions and obtain the steady state result as shown in reference (Borghi *et al.*, 1996).

Fig. 2 shows the curves calculated by the scheme in this letter with  $\theta_{in} = 90^\circ$  and  $\theta_{in} = 120^\circ$ , where (a) are the time domain response in the directions of  $\varphi = 30^\circ$ ,

90° and 150°, (b) are the corresponding broadband response by using the Fourier transform, and (c) are the extracted data in various directions for 300MHz (meeting  $ka = \pi$  and  $kh = 2\pi$ ). In the case of  $\theta_{in} = 90^\circ$ , the response in  $\varphi = 30^\circ$  and  $\varphi = 150^\circ$  are entirely coincidence for the symmetry of the model and the incident wave direction.

Fig. 2(c) can be compared with the dashed curves in Fig. 6 with  $n=2$  reported by Borghi *et al.* (1996). The results are identical except that there is no specified information of amplitude in the latter case.



(c) FREQUENCY RESPONSE VERSE AZIMUTH WITH  $\theta_{in} = 90^\circ$  AND  $\theta_{in} = 120^\circ$

FIG. 2 FAR FIELD RESPONSE FOR A PEC CIRCULAR CYLINDER ABOVE THE INTERFACE.

## Conclusion

A direct time-domain extrapolation to the far field in half-space to calculate the broadband response has been proposed based on the theory of electromagnetic wave propagation, which was the improvement of the method proposed by Luebbers *et al.* (1992) and Garcia *et al.* (2000), named as the time-domain three-wave extrapolation. Results have been obtained to validate the scheme in this letters.

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## REFERENCES

Allen Taflove, Susan C. Hagness. Computational

- electrodynamics: the finite-difference time-domain method. London: Artech House, 2005.
- Bill Wong P., Leonard Tyler G., John E. Baron et al. "A three-wave FDTD approach to surface scattering with applications to remote sensing of geophysical surfaces." *IEEE Trans. Antennas Propagat.*, 1996, 44(4): 504-514.
- Borghi R., Gori F., and Santarsiero M. "Plane-wave scattering by a perfectly conducting circular cylinder near a plane surface: cylindrical-wave approach." *J. Opt. Soc. Am.*, 1996, 13(3): 483-493.
- Gonzalez Garcia S., Garcia Olmedo B. and Gomez Martin R. "A time-domain near- to far-field transformation for FDTD in two dimensions." *Microw. Opt. Technol. Lett.*, 2000, 27(6): 427-432.
- Ilker R. Capoglu and Glenn S. Smith. "A Direct Time-Domain Near-Field to Far-Field Transform for the FDTD Analysis of Radiation in the Presence of an Infinite Grounded Dielectric Slab." *IEEE Trans. Antennas Propag.*, 2006, 54(12): 3805-3814.
- Kane S. Yee, David Ingham, and Kurt Shlager. "Time-domain extrapolation to the far field based on FDTD calculations." *IEEE Trans. Antennas Propagat.*, 1991, 39(3): 410-413.
- Kenneth Demarest, Zhubo Huang, and Richard Plumb. "An FDTD near- to far-zone transformation for scatterers buried in stratified grounds." *IEEE Trans. Antennas Propagat.*, 1996, 44(8): 1150-1156.
- Martin T. and Pettersson L. "FDTD time domain near-to-far-zone transformation above a lossy dielectric half-space." *Appl. Comput. Electromagn. Soc. J.*, 2001, 16(1): 45-52.
- Raymond Luebbers, Deirdre Ryan, and John Beggs. "A two-dimensional time-domain near-zone to far-zone transformation." *IEEE Trans. Antennas Propagat.*, 1992, 40(7): 848-851.
- Roger F. Harrington. *Time-Harmonic Electromagnetic Fields*. New York: IEEE Press, 2001.
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